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A Multi-objective Cash-in-transit Pollution-location-routing Problem Based on Urban Traffic Conditions

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ABSTRACT

Cash transfer from the central treasury to the bank branches and automated teller machines (ATMs) all over the city is one of the vital processes in a banking system. There are multiple factors (e.g., location of the treasury, transportation fleet, geographic distribution of the branches and ATMs, the demand for cash, customer satisfaction, and traffic that influence the efficiency of the cash transfer). Moreover, environmental issues, and in particular the issue of greenhouse gas (GHG) emissions are given weight. In this paper, a new mathematical model for a location-routing problem with transport vehicles in the banking system is developed based on urban traffic in such a way that three objectives of decreasing greenhouse emissions, reducing location and routing costs, and increasing customer satisfaction are taken into consideration simultaneously. Furthermore, a new multi-objective genetic algorithm hybridized with a PROMETHEE method, namely the multi-objective genetic-PROMETHEE algorithm (MOGPA), is developed to tackle the proposed model. The efficiency of the proposed algorithm is examined by comparing it with the non-dominated sorting genetic algorithm (NSGA-II) and multi-objective imperialist competitive algorithm (MOICA) for the real-case issue of Saman Bank. Because management assumptions are considered in the preference functions of the proposed algorithm, the results show that the solutions of the proposed algorithm are more efficient and closer to reality.

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NOMENCLATURE

Indices:			
$N_\circ = \{1,...,m\}$	Set of treasuries	$K = \{1,...,k\}$	Set of vehicles
$N_c = \{1,...,n\}$	Set of customers	$T = \{1,...,t\}$	Set of periods
$N_T = N_\circ \cup N_c$	Set of nodes	$R = \{1,2,3...r\}$	Set of speeds
$A = \{(i,j)\}$	Set of arcs		
Parameters:			
$K_\circ$	Engine friction factor		
N	Engine speed	C_i	Capacity of treasury i
V	Engine displacement	Q_k	Capacity of vehicle k
β	Vehicle-specific constant	G_i	Fixed cost of building a treasury i
α	Vehicle-arc specific constant	$PLDT$	Maximum possible travel time
M_k^w	Total vehicle weight	ET	Earliest time to start the cash transfer process
M^f	Weight of one million Rials	LT	Latest CIT vehicle return time
PR	Total salary of driver, cashier, and law enforcement officer (per second)	d_{ij}	Distance between two nodes i and j

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H_k	Variable CIT vehicle costs	q_j	Demand of customer *j*
F_k	Fixed cost for CIT vehicles *k*	s_j	Service time of customer *j*
$\left[e_j, l_j\right]$	Soft time window for costumer *j*	ts_t	Start time for traffic time interval *t*
$\left[EET_j, ELT_j\right]$	Hard time window for costumer *j*	v_{ij}^{tr}	Discretized speed defined by *r* non-decreasing speed levels in period *t*
Decision variables:			
f_{ij}^{k}	Amount of commodity on board of vehicle *k* traverses from *i* to *j*	y_i	1 if treasury *i* is opened; 0, otherwise
p_{ij}^{k}	Travel time from node *i* to node *j* by vehicle *k*	u_{ij}	1 if treasury *i* serves customer *j*; 0, otherwise
tt^k	Total travel time for vehicles *k*	x_{ij}^{k}	1 if vehicle *k* traverses from i to *j*; 0, otherwise
a_j	Start time to customer service *j*	z_{ij}^{ktr}	1 if vehicle *k* traverses from i to *j* in the period *t* with speed *r*; 0, otherwise
w_{il} , o_{il}	Variables of piece linear functions	SL_j	Satisfaction for customer *j*

1. INTRODUCTION

As the main body of the modern financial system, the banking system plays a significant role in sustainable growth as well as organizational adjustment and sustainable development of the economy. Cash transfer from the central treasury to the customers (branches of the bank, automated teller machines (ATMs), and large retailers) is among the vital processes of the banking system. On a global size, cash keeps being the common medium of payment in transactions. This instrument is the final source to finance transactions, especially in low-value purchases. The recent report by the Federal Reserve on the payment and business habits of the people in the United States shows that 26% of the total transactions and 40% of the payments ranging from \$10 to \$25 in 2019 were in cash [1]. Despite the support of the legislators in the usage and propagation of non-cash transactions, cash in circulation has experienced consistent growth in recent years. The amount of cash swirling in the United States has increased by 80%, between 2010 to 2019 [1]. In Iran, cash circulation is high and six of ten transactions are performed by cash. The issue of cash-in-transit (CIT) is generally one of the application areas in vehicle routing problems (VRPs) for the transportation of valuable goods including cash in areas such as populated cities or metropolitans; hence it has been a popular topic in various recent studies.

The high volume of cash and valuable goods which are in demand every day should be transferred between the treasury of the bank branches, the ATMs, and large retailers. The main limitation of the cash transit network is in the delivery and collection of cash within the timeframe. Bank branches have a limited time in the working day and security rules of the Central Bank further limit this process within the set timeframe. On top of that, we are faced with the issue of a VRP with a time window (VRPTW). Regular delivery has to happen before 12:30 and its collection before 3:00. Thus, we are faced with a hard time window. On the other hand, should the required amount of cash be not provided within the desired timeframe, apart from a loss in the fee, the bank will suffer from customer dissatisfaction with the services. So, we have also faced a soft timeframe window. Customers of the treasury are categorized into three groups; i.e., bank branches, ATMs, and large retailers. ATMs have demands for cash, retailers request for the delivery of the surplus cash and the branches can have either of these two from the treasury. It is noteworthy that on a typical day a branch can ask for cash pick-up or delivery of the surplus cash.

Traffic congestion is an important issue for logistics companies in urban areas. This growing phenomenon increasingly influences the pace of traveling during peak times. Traffic congestion usually happens in key traffic nodes, e.g., intersections, overpasses, and tunnels which can result in serious challenges for the routing optimization of the vehicles. To capture the impact of traffic congestion, the time-dependent VRP (TDVRP) is introduced in the literature. This problem considers traffic patterns throughout the day in which the pattern of alternating speed according to a predictable rhythm is exerted; this is aimed to determine the average speed of movement from one period to another. There have been few studies on the transfer of valuable commodities regarding traffic conditions. This underestimation of traffic congestion may result in inexact planning decisions as the significance of the time factor in traffic is disregarded.

In bigger banks due to the wider distribution of branches in megacities, cash delivery is handled through multiple treasuries to various branches so deciding on the proper location of the treasuries is one of the most important decisions in the process of any cash delivery [2]. The location of the treasury is selected from several nominated points which are the very branches of the bank. Each treasury possesses several CIT vehicles and independent facilities so we are faced with a location-routing problem (LRP). As the name suggests, making decisions on the facilities (e.g., factories, storehouses, and distribution centers) have been amalgamated with the decision-making on routing. It goes without saying that if any of these matters are studied independently and separately from the other ones, it may lead to inefficient results. The LRP has various applications in the supply chain network design, tactical planning, and healthcare systems [3-5].

The objective of most banks so far has been to minimize risk, cost, and time. Every day gargantuan volumes of cash are transferred to delivery vehicles, which has multiple risks including robbery. To control this risk, special security standards are put in place for the transfer of cash in local, regional, and national statutes. In other words, the process of cash delivery must be done through routes verified by the police, and the vehicles, which carry the cash must enjoy certain standards. Banks also need to ensure the cash delivery vehicles through insurance companies to control the risk (cash is usually carried by armored vehicles). It is worth noting that in this process, the volume of the cash must not exceed the set cap which is determined by the insurer. Hence if something happens through the process of cash delivery, the insurance company will sustain the risk. Regarding what has been said so far and because of outsourcing the risk of the cash delivery process to insurance companies, in this study unlike many previous ones, the risk objective function has not been used.

In recent years, social demand has been on the increase regarding environmental issues. In Iran, the most outstanding crisis in the discussion about pollution is the suspended particles with a size of fewer than 2.5 microns, which take the biggest share of the pollutants in cities, which in turn mostly emanate from older vehicles, which are in demand of renovation and repair. Recently the Environment Organization passed the clean air rule some parts of which have not yet been enforced, e.g., upgrading the obligatory standard of vehicles to Euro 5, and renovating the old transport fleet of the country which could have affected air pollution conspicuously. In addition, as air pollution increases daily due to its effects on social health passing such legislation shortly is not far-fetched. So, amelioration and renovation of the cash delivery fleet is not only a social responsibility but also represents a futuristic measure. Thus, in this article, the matter of cash delivery has been reviewed regarding the existing environmental issues and corresponding green objectives have been incorporated. Apart from the futuristic attitude to social responsibility, customer orientation in banks is an inevitable principle which all the more highlights the need to pace up providing services, like the cash delivery process.

In this paper, a multi-objective model of a location-routing problem is presented after considering the traffic conditions and with the objectives of reducing costs, as well as greenhouse emissions and increasing customer satisfaction (along with decreasing the time of cash delivery), which is considered a valuable commodity. To solve this model, a novel and metaheuristic algorithm with various objectives has been presented by hybridizing the PROMETHEE method and genetic algorithm.

The remaining parts of this paper are organized as follows. In section 2, the studies in this regard for the identification of key points and a study gap are reviewed. In section 3, the mathematical model is explicated through traffic conditions. In section 4, the solution method is offered. In section 5, the proposed problem-solving methodology is analyzed via a real-life case of cash distribution. Finally, in section 6 the key findings of this research plus grounds for future ones are touched on.

2. LITERATURE REVIEW

The vehicle routing problem with time windows is a kind of a classical VRP. Considering time windows in routing is one of the methods which contributes to making this closer to real life. This problem when was first offered by Bodin et al. [6] in 1983. In cases where there are time windows, giving services to each customer must be done within a specific time frame. This becomes all the more important considering the importance of time in providing a solution in practice. Among its applications is cash transfer in banks as well as transportation of valuable commodities. A cash-in-transit VRP (CTVRP) has derived from the traditional VRPTW, yet enjoys its unique characteristics. As CIT vehicles carry cash and other valuables, there have been many studies on them. Talarico et al. [7] solved a case of VRPTW and limitations related to the risk of cash transfer via two metaheuristic algorithms. General limitation guarantees that the overall risk does not exceed the threshold of risk. Talarico et al. [8] suggested a risk-constrained CTVRP (RCTVRP) and defined the risk of the route as the function related to the probability of a robbery, the probability of a successful robbery, and the quantitative loss after the robbery happens.

Talarico et al. [9] put forth a CVRP model with a risk limitation, in which risk was dependent on the transferred cash as well as the covered distance. For smaller samples, the model was using CPLEX and for bigger ones, two metaheuristic methods were exploited. Talarico et al. [10] developed a VRP model with two objectives minimizing costs as well as minimizing the maximum risk for solving the model, they used a combination of a metaheuristic method and a multi-criteria decision-making (MCDM) method. Bozkaya et al. [11] offered a model to decrease valuables transfer risk considering two criteria of socioeconomic risk as well as risk based on using a link. This model is solved by an adaptive large neighborhood search (ALNS) algorithm. To solve the RCTVRP, Radojičić et al. [12] designed a greedy randomized adaptive search procedure hybridized with path relinking methodology and constructed a new data structure to reduce the time complexity. Ghannadpour and Zandiyeh [13] developed a new multi-objective game theory-based model to increase the security of cash-in-transit. For this objective and to reduce transportation costs, a bi-objective vehicle routing problem with a time window (VRPTW) is developed where the risk of transfers and the distance traveled by vehicles is minimized. To better estimate the robber's performance, the probability of a robber's ambush is calculated by the game theory approach. Moreover, a new multi-objective hybrid genetic algorithm incorporated with some new heuristics and operators is developed. Fallahtafti et al. [14] suggested a location-routing framework with two objectives based on risk and the cost of transport and to solve it they used various precise and metaheuristic methods.

Although the aforementioned studies reached useful results regarding the CTVRP, they had not considered road traffic especially traffic networks inside cities, so developing a model that can encompass urban traffic is a pre-requirement. Also, there are researches in which there is a presupposition that time is not a definite factor in solving CTVRP traveling between traffic nodes. Chang [15] proposed a CTVRP model with stochastic travel time to formulate the variant distribution plans and to reduce the risk of robbery by using the time-space network flow technique. Within the same context, Yan et al. [16] established an RCTVRP model by using the time-space network technology. Mathematical programming software and decomposition/collapsing technology were employed to solve the model.

Boonsam et al. [17] studied assignment problems and VRPTW, taking Bangkok bank (Thailand) as an example. Three heuristic algorithms were used to address the problems, aiming to improve distribution efficiency by utilizing existing resources. Tikani et al. [18] offered a new model for CIT which put forth that as transport risk is proportional to the travel time of the vehicle, a formula for measuring the transport risk of traffic congestion was needed. To solve this model, they suggested flexible restricted dynamic programming and a self-adaptive caching genetic algorithm. Tikani et al. [19] came up with three objectives, including completion times, risk of robbery, and customers' satisfaction level considering the effects of traffic congestion as a daily phenomenon. Jin et al. [20] improved a bi-objective model of the CTVRP, including both the economic and environmental objectives based on real-time traffic data, and designs the nearest neighbor-first iterated local search-second (NN-ILS) algorithm.

These studies considered road traffic conditions solely based on routing. Regarding traffic conditions, the proper location of the treasuries can have a considerable impact on valuable commodities and cash transfers. Simultaneous study of the location of the treasuries and proper routing for valuables and cash about the traffic can be deemed as a gap in research in this area.

In recent years, environmental issues have attracted more attention as above said and as road transport is among the biggest producers of greenhouse gases which in turn contribute to CO_2 emissions, which trigger global warming and all this is in direct connection with fuel consumption of the vehicles, special attention has been and needs to be given this issue [21-23]. The amount of fossil fuel consumed by vehicles is dependent on factors such as velocity, acceleration, workload, quality of the road, type of vehicles, as well as traffic issues. A Pollution and Routing Problem (PRP) was initially introduced by Bektas and Laporte [24] which was a boosted version of the classical VRP within a time window that comprised routing for vehicles that are used for giving services to a group of customers and determining the speed of which is of significant importance to lower fuel costs, driver fees as well as the dissemination of greenhouse gases (GHGs). In this paper, a location-routing model with multiple objectives aiming at decreasing GHGs as well as costs on the one hand, and increasing customer satisfaction through considering traffic matters on the other are presented while weighing the issue of valuables' transport. Among the most important innovations of this paper are the modeling and the presentation of a meta-heuristic algorithm enjoying multiple objectives for the problem solutions.

3. PROBLEM DEFINITION

3. 1. Problem Description

In this section, the problem will be clarified initially through the definition of the suppositions that have been considered.

- The problem has been designed as a discrete network in which the locations of the treasuries must be close to the branches; branches, ATMs, and large retailers are considered nodes.
- The customers of the treasury are three groups (i.e., branches, ATMs, and large retailers).
- Two main activities, which are cash delivery and surplus cash collection, are done through cash transit vehicles.
- The demands of the customers are considered as clear and definite.
- Each cash transit vehicle starts moving from treasury and after going through a certain route, returns to its original location. It is noteworthy that deficiency is not allowed and that the demands of each of the customers must be met by one vehicle and within one visit. Cash transit vehicles are all the same and sustain fuel costs, depreciation costs, maintenance costs as well as manpower expenditures. Typically,

when a cash transit vehicle is used, there should be a driver, two cash deliverers, and two police officers.

- The treasuries and the vehicles do not have capacity limitations as cash is not bulky. However, because of the limitations of the demand that customers can have as well as the insurer's defined cap, plus security considerations, the maximum amount of cash, which can be transferred through each vehicle must be determined and clarified.
- Soft and hard time windows should be defined for each customer. Giving services outside the hard time window is not viable; nevertheless, doing so outside the soft time vehicle window is allowed but can result in customer dissatisfaction .
- To take route traffic into account, cash delivery is divided into t timeframes. As traffic is deemed consistent by Bektas and Laporte [24], the alternative speed for each timeframe has been regarded as r. The model is defined in a way that only one alternative of speed within the timeframe of t is passed by a vehicle over a specific arc.

3. 2. Mathematical Model In this section, a routing and location model is offered to reduce costs, decrease GHG emissions, and increase customer satisfaction by decreasing the time of cash delivery within the cash transfer network of Saman Bank. To do this, capacity limitations and soft and hard time windows have been taken into account for each of the customers of the bank treasury.

$$\begin{aligned}\text{Min } OF_1 = {} & NVK_{\circ}\lambda \sum_{i\in N_T}\sum_{j\in N_T}\sum_{k\in K}\sum_{t\in T}\sum_{r\in R} d_{ij} z_{ij}^{ktr} / v_{ij}^{tr} \\ & + \beta\gamma\lambda \sum_{i\in N_T}\sum_{j\in N_T}\sum_{k\in K}\sum_{t\in T}\sum_{r\in R} d_{ij} z_{ij}^{ktr} / (v_{ij}^{tr})^2 \\ & + \gamma\lambda \sum_{k\in K}\sum_{i\in N_T}\sum_{j\in N_T} M_k^w \alpha_{ij} d_{ij} x_{ij}^k \\ & + \gamma\lambda \sum_{k\in K}\sum_{i\in N_T}\sum_{j\in N_T} M^f \alpha_{ij} d_{ij} f_{ij}^k\end{aligned} \tag{1}$$

$$\begin{aligned}\text{Min } OF_2 = {} & \sum_{i\in N_\circ} G_i y_i + \sum_{k\in K} (PR + H_k) tt^k \\ & + \sum_{k\in K}\sum_{j\in N_c}\sum_{i\in N_\circ} F_k x_{ij}^k\end{aligned} \tag{2}$$

$$\text{Max } OF_3 = \sum_{j\in N_c} SL_j \tag{3}$$

s.t.

$$SL_j = w_{j2} + w_{j3} \qquad \forall j \in N_c \tag{4}$$

$$\begin{aligned} a_j = {} & EET_j \times w_{j1} + e_j \times w_{j2} \\ & + l_j \times w_{j3} + ELT_j \times w_{j4}\end{aligned} \qquad \forall j \in N_c \tag{5}$$

$$\sum_{l=1}^{4} w_{jl} = 1 \qquad \forall j \in N_c \tag{6}$$

$$\sum_{l=1}^{4} o_{jl} = 1 \qquad \forall j \in N_c \tag{7}$$

$$w_{j1} \le o_{j1} \qquad \forall j \in N_c \tag{8}$$

$$w_{j2} \le o_{j1} + o_{j2} \qquad \forall j \in N_c \tag{9}$$

$$w_{j3} \le o_{j2} + o_{j3} \qquad \forall j \in N_c \tag{10}$$

$$w_{j4} \le o_{j3} + o_{j4} \qquad \forall j \in N_c \tag{11}$$

$$\sum_{i\in N_\circ} u_{ij} = 1 \qquad \forall j \in N_c \tag{12}$$

$$\sum_{j\in N_c} \left(\frac{q_j + |q_j|}{2}\right) u_{ij} \le C_i y_i \qquad \forall i \in N_\circ \tag{13}$$

$$\sum_{j\in N_c} \left(\frac{|q_j| - q_j}{2}\right) u_{ij} \le C_i y_i \qquad \forall i \in N_\circ \tag{14}$$

$$\sum_{j\in N_c} \left(\frac{q_j + |q_j|}{2}\right) u_{ij} = \sum_{k\in K}\sum_{j\in N_c} f_{ij}^k \qquad \forall i \in N_\circ \tag{15}$$

$$\sum_{j\in N_c} \left(\frac{|q_j| - q_j}{2}\right) u_{ij} = \sum_{k\in K}\sum_{j\in N_c} f_{ji}^k \qquad \forall i \in N_\circ \tag{16}$$

$$\sum_{k\in K} x_{ij}^k \le u_{ij} \qquad \forall i \in N_\circ, j \in N_c \tag{17}$$

$$\sum_{k\in K} x_{ji}^k \le u_{ij} \qquad \forall i \in N_\circ, j \in N_c \tag{18}$$

$$\sum_{k\in K} x_{ij}^k + u_{kj} + \sum_{\substack{m\in N_\circ \\ m\ne k}} u_{mj} \le 2 \qquad \forall k \in N_\circ, i, j \in N_c, i \ne j \tag{19}$$

$$\sum_{k\in K}\sum_{i\in N_T} x_{ji}^k = 1 \qquad \forall j \in N_c \tag{20}$$

$$\sum_{k\in K}\sum_{i\in N_T} x_{ij}^k = 1 \qquad \forall j \in N_c \tag{21}$$

$$\sum_{j\in N_c}\sum_{i\in N_\circ} f_{ij}^k = \sum_{\substack{m\in N_T \\ m\ne j}}\sum_{j\in N_c} x_{mj}^k \left(\frac{q_j + |q_j|}{2}\right) \qquad \forall k \in K \tag{22}$$

$$\sum_{j\in N_c}\sum_{i\in N_\circ} f_{ji}^k = \sum_{\substack{m\in N_T\\ m\neq j}}\sum_{j\in N_c} x_{mj}^k\left(\frac{|q_j|-q_j}{2}\right) \qquad \forall k\in K\,. \tag{23}$$

$$\sum_{k\in K}\sum_{i\in N_T} f_{ij}^k - \sum_{k\in k}\sum_{i\in N_T} f_{ji}^k = q_j \qquad j\in N_c \tag{24}$$

$$\left(\frac{q_j+|q_j|}{2}\right)x_{ij}^k \le f_{ij}^k \qquad \forall i\in N_T, j\in N_c, k\in K \tag{25}$$

$$\left(\frac{|q_j|-q_j}{2}\right)x_{ji}^k \le f_{ji}^k \qquad \forall i\in N_T, j\in N_c, k\in K \tag{26}$$

$$\left(Q_k - \left(\frac{q_j+|q_j|}{2}\right)\right)x_{ji}^k \ge f_{ji}^k \qquad \forall j\in N_c, i\in N_T, k\in K \tag{27}$$

$$\left(Q_k - \left(\frac{|q_j|-q_j}{2}\right)\right)x_{ij}^k \ge f_{ij}^k \qquad \forall j\in N_c, i\in N_T, k\in K \tag{28}$$

$$Q_k x_{ij}^k \ge f_{ij}^k \qquad \forall i\in N_\circ, j\in N_c, k\in K \tag{29}$$

$$Q_k x_{ji}^k \ge f_{ji}^k \qquad \forall i\in N_\circ, j\in N_c, k\in K \tag{30}$$

$$\sum_{\substack{h\in K\\ h\neq k}}\sum_{\substack{m\in N_T\\ m\neq j}} x_{jm}^h + x_{ij}^k \le 1 \qquad \forall i\in N_\circ, j\in N_c, i\neq j, k\in K \tag{31}$$

$$\sum_{t\in T}\sum_{r\in R} z_{ij}^{ktr} = x_{ij}^k \qquad \forall (i,j)\in A, k\in K \tag{32}$$

$$\sum_{r\in R}\sum_{t\in T}\sum_{k\in K}\sum_{i\in N_T}\frac{d_{ij}}{v_{ijtr}} z_{ij}^{ktr} + \sum_{k\in K}\sum_{i\in N_T} p_{ij}^k \le a_j \qquad \forall j\in N_c \tag{33}$$

$$\sum_{k\in K}\sum_{i\in N_T} p_{ji}^k \ge a_j + s_j \qquad \forall j\in N_c \tag{34}$$

$$ts_{t+1}\sum_{r\in R} z_{ij}^{ktr} + PLDT(1-\sum_{r\in R} z_{ij}^{ktr}) \ge p_{ij}^k \qquad \forall (i,j)\in A,\ k\in K, t\in T \tag{35}$$

$$ts_t\sum_{r\in R} z_{ij}^{ktr} \le p_{ij}^k \qquad \forall (i,j)\in A, k\in K, t\in T \tag{36}$$

$$p_{ij}^k \ge ET\times x_{ij}^k \qquad \forall i\in N_\circ, j\in N_c, k\in K \tag{37}$$

$$EET_j \le a_j \le ELT_j \qquad \forall j\in N_c \tag{38}$$

$$p_{ij}^k \le PLDT\times x_{ij}^k \qquad \forall (i,j)\in A, k\in K \tag{39}$$

$$\sum_{r\in R}\sum_{t\in T}\sum_{i\in N_\circ}\frac{d_{ji}}{v_{ijtr}} z_{ji}^{ktr} + \sum_{i\in N_\circ} p_{ji}^k \le tt^k \qquad \forall j\in N_c, \forall k\in K \tag{40}$$

$$tt^k \le LT \qquad \forall k\in K \tag{41}$$

$$x_{ij}^k \in \{0,1\} \qquad \forall (i,j)\in A, k\in K \tag{42}$$

$$z_{ij}^{ktr} \in \{0,1\} \qquad \forall (i,j)\in A, k\in K, t\in T, r\in R \tag{43}$$

$$y_i \in \{0,1\} \qquad \forall i\in N_\circ \tag{44}$$

$$u_{ij} \in \{0,1\} \qquad \forall i\in N_\circ, j\in N_c \tag{45}$$

$$f_{ij}^k, p_{ij}^k \ge 0 \qquad \forall (i,j)\in A, k\in K \tag{46}$$

$$a_j \ge 0 \qquad \forall j\in N_c \tag{47}$$

$$tt^k \ge 0 \qquad \forall k\in K \tag{48}$$

$$w_{jl} \ge 0 \qquad \forall j\in N_c, l\in\{1,2,3,4\} \tag{49}$$

$$o_{jl} \in \{0,1\} \qquad \forall j\in N_c, l\in\{1,2,3,4\} \tag{50}$$

In the mathematical model of the problem, the first objective function (1) minimizes the emission of greenhouse gases. The objective function of fuel consumption is based on the comprehensive model of distribution which was professed by Demir et al. [25]. What is considered the second objective function (2) as a whole is defined as the stable costs of the treasury, operational costs within the cash transfer team, as well as stable and alternating costs of using cash transfer vehicles which have to be minimized. The third objective function (3) is considered to be customer satisfaction, which must be maximized. In this paper, by using a trapezoidal fuzzy function, hard and soft time windows are changing to the concept of customer satisfaction in a way that exceeds the time defined through these time windows resulting in customer dissatisfaction; Figure 1 displays this concept.

Constraints (4) to (11) represent the linearization constraints of the customer satisfaction function using Piece Linear Functions (PLFs). Constraint (12) guarantees that only one treasury is allotted to each customer. Constraints (13) and (14) state that the cash demands of the customers who are being catered for through one treasury must be lower than its capacity.

Moreover, the collected cash from the branches must be less than the capacity of the treasury. It is noteworthy that a positive demand for cash illustrates the demand for receiving cash from the treasury and a negative level of it displays cash surplus return to the treasury. Constraint (15) shows that the cash that is taken out of a treasury through all its specialized CIT vehicles is equal to the demand of all the customers from the treasury, which they had asked requested. This is all not to mention that Constraint (16) that presents the cash which enters it through all its specialized vehicles, is equal to the demands of all the customers that are specifically dealing with that treasury and have asked for the pickup of surplus cash.

Constraints (17) to (19) depict that cash transfer operations start from one treasury and finish at the same place. Constraints (20) and (21) are used to make sure that each node is met only once; in other words, the demands of one customer are catered for all at once and by the same vehicle. Constraints (22) and (23) show that the total load that exits a typical treasury is equal to the aggregate of all the demands of the customers that asked for cash and are being given services by that vehicle. Constraint (24) is the difference between the entrance and the exit of the nodes which is equal to the demand; in other words, this limitation balances commodity flow in each node and in this way discards the sub-tours to make sure that the request of the customer is met accordingly. Constraints (25) and (26) state that once a customer asks for cash, the amount of cash that is transferred by the cash transit vehicle must be more or equal to the specific customer's demand, and should the customer want to return any surplus cash, the cash, which is transferred by the vehicle on the next trip should be more or equal to the cash that was initially provided with.

Constraints (27) to (30) put forth that each customer must be allocated to one vehicle and it must be guaranteed and checked that the amount of cash that is carried through a specific vehicle does not ever exceed the insurance limit. Constraint (31) states that each customer must be linked to one cash transfer vehicle. Constraint (32) states that each parabola just uses dimension j of speed. Constraint (33) states that if node j is met after node i, the time of meeting node j is equal to the total time of movement from node i to node j and the time spent between i and j. Constraint (34) displays that the time spent from node i to node j, is bigger than the entrance time to node i, and the time of giving service at node i. Constraints (35) and (36) display that the time of movement is proportionate to the time frame spent in traffic. Constraint (37) states that the time of departure for every vehicle from the treasury must be bigger than the earliest time of service provision by the treasury.

Constraint (38) is a hard time window constraint. In other words, it delimits the time of service to the customer more stringently. Constraint 39 guarantees that the time of movement from i to j by vehicle k has a non-zero amount only if its corresponding determining alternative is tantamount to 1 and the maximum level of the time of movement is commensurate to the stable quantity of PLDT. Constraint (40) shows that the time spent by vehicle k is equal to the aggregate time of moving from the last customer toward the treasury and the time spent on the way. Constraint (41) ensures that the return time of each vehicle to the treasury is before the last service is done. Constraints (42) to (50) determine the type of variables used in the model.

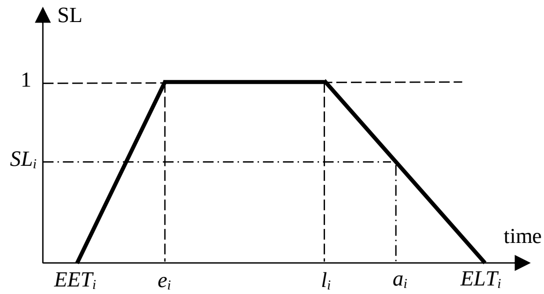

Figure 1. Satisfaction level for fuzzy time windows

4. SOLUTION APPROACH

The location and pollution-routing problem is an NP-hard problem that cannot be solved through typical optimization methods and the situation persists even for the smaller and simpler samples. One solution for such problems is using metaheuristic algorithms. In this section, a new multi-objective meta-heuristic algorithm for the defined problem is proposed.

4. 1. Multi-objective Genetic-PROMETHEE Algorithm Genetic algorithms have one objective by essence. Some researchers have developed this algorithm for multi-objective problems out of which we can name NSGA-II, NRGA, and AFDGA [26-28]. Through blending the genetic and meta-heuristic algorithm with the PROMETHEE method, we are after undominated solutions which can comprise some of the decision-making characteristics within them. Such characteristics include the weight of the objectives and the function of their preference. The PROMETHEE method, as a functional one, has two words of preference and indifference it in, is after the best options. This method was first suggested by Brans [29]. In this paper, the PROMETHEE-II method is used, which rates discrete options thoroughly. In the suggested method, like the genetic algorithm, some solutions are initially generated randomly that are called first-generation parents.

The problem is a multi-objective one. The parents are assessed and rated by the PROMETHEE method. Afterward, based on the roulette wheel some of the parents are chosen to reproduce children and do the intersection operation. Upon the reproduction of the children, the population of the parents will be mixed with them and then the nondominated population will be added to the archive which will be in turn updated. The population inside the archive will be studied in terms of prominence and the solutions which can dominate others are eliminated. Moreover, in the population of the archive, the operation of eliminating similar solutions is exerted. If the size of the archive is bigger than the defined size, the solutions will be arrayed within it by using the PROMETHEE method and redundant solutions will be eliminated. In this algorithm, the size of the archive will be shown via nArchive. Furthermore, the blended population will be rated by the PROMETHEE method, the best will be transferred to the next generation only in proportionate to the initial population. This process will carry on until the precondition is reached. The stages of the multi-objective genetic-PROMETHEE algorithm (MOGPA) are shown in Figure 2.

As it is clear the functionality of an algorithm and the quality of the output solutions are completely dependent on the way the solutions are displayed in the possible area. Moreover, solution representation must be in a way that the audience can easily and freely search through them. In this paper, there has been the best use of a continuous representation for location and routing. In this representation and a simultaneous fashion of the location of the treasuries, the way customers are allotted to them, and also the route for service provision for each customer via the CIT vehicles have been shown. While the nominated location for the treasury is shown as *m*, the customer is represented by *n* with the transit vehicle being labeled as *k*.

Should the solution be shown as two lines, then *n* would be an integer. The first chain of integers is in the range of [l, *k*+1). The integer in each figure presents the way each customer is served via a vehicle and the decimal part shows the sequence of the services in a way that smaller numbers have a higher priority. As for the way treasuries are built and the point from which each vehicle should set out, there is a need to calculate all the numbers, whose integer parts are equal so that we can come up with a mean number. Then, the decimal part of them may show the position of the treasury. If the decimal part is within the range of $[0,1/m)$, it is the first treasury and if it is in the range of $[1/m,2/m)$, it will be the second treasury. Likewise, if it is within the range of $[(m-1)/m,1)$, *m* will be the starting point of the vehicles.

It shows after the vehicle delivers its required services, what speed will it use to reach customer *n*. So, the decimal segment of the figure is divided into *r* equal parts each of which represents a separate speed. In Figure 3, the solution along with its schematic form for a problem of 10 customers, 4 nominated locations for the treasury, and 5 CIT vehicles is shown.

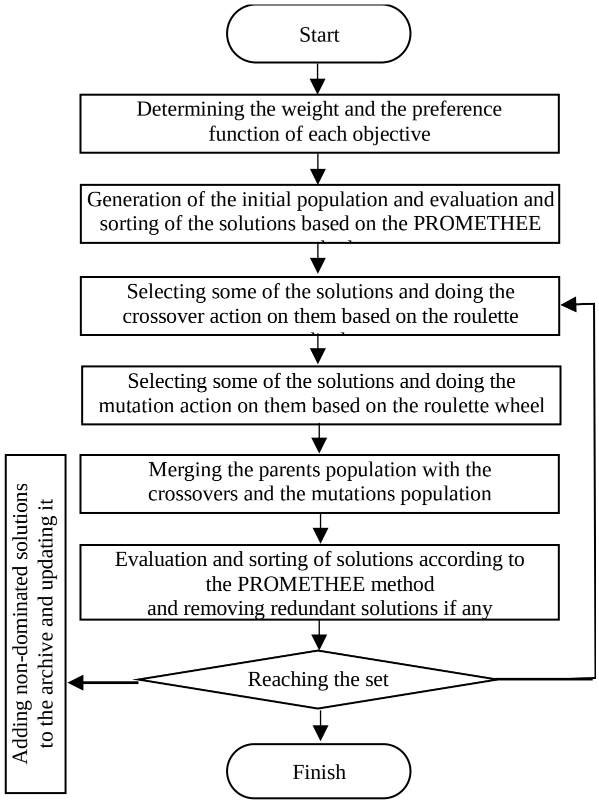

Figure 2. Flowchart of the MOGPA

The second line of integers will be in the range of $[1,r+1)$, in which the integer part shows if the vehicle leaves to any customer, which of the discrete part of speed will be used within that time.

In the suggested algorithm, three crossover operators (i.e., one-point, two-point, and uniform) are used to solve the problem. Moreover, four methods of insertion, swap, reversion, and perturbation for genetic mutation are used. The condition to halt the algorithm is to reach a certain number of function evaluations (NFE's).

1	2	3	4	5	6	7	8	9	10
3.09	5.72	2.69	1.56	2.21	1.66	3.88	2.77	1.22	4.66
4.69	1.28	1.42	4.21	2.03	2.51	2.37	2.52	1.45	2.83

	Average	Treasury
Vehicle 1	1.48	2
Vehicle 2	2.56	3
Vehicle 3	3.49	2
Vehicle 4	4.66	3
Vehicle 5	5.72	3

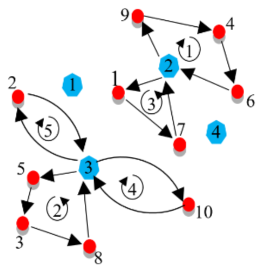

Figure 3. Solution representation and its schematic form

4. 2. Comparison Metrics for Algorithm Evaluation Studying the function of multi-objective algorithms is much more complicated than that of single-objective algorithms in a way that one assessment indicator alone will not suffice to study all the acquired responses for the presented algorithms. Hence, in this paper, to assess the quality of the solutions for the suggested algorithms, Pareto solutions attained from the suggested algorithm are compared with NSGA-II [26] and multi-objective imperialist competitive algorithm (MOICA) [30] algorithms having six indices of quality metric, mean ideal distance [31], spacing metric, diversification metric, data envelopment metric [32], and PROMETHEE metric [29].

4. 3. Parameters Tuning the design and adjustments of its parameters in a way that different quantities of the algorithm parameters may result in different solutions with totally different qualities. So, if the parameters are not tuned correctly, we cannot reach optimal solutions. In this paper, to tune the parameters, a response surface methodology (RSM) is used. The related parameters and their levels are shown in Table 1. Then, the selected parameters are summarized in Table 2.

5. COMPUTATIONAL RESULTS

To assess the functionality of the suggested algorithm, three problems with various scales based on real-life situations of Saman Bank are used (Table 3), which were in congruence with the real data of the bank. All these matters are related to cash delivery to Rial (local currency) branches of Isfahan, Mashhad, and Tabriz. All through the project the maps of the afore-cited cities which entailed the required information - for instance, potential locations to established treasuries, the locations of the branches, the ATMs, and the retailers of the bank along with the routes among the nodes - were made use of. Generally, the cash balance of the branches and the ATMs were systematically monitored and if at the end of the working day the balance or one of the centers was lower than the required minimum, the order to request cash would be put in place at the beginning of the next working day. Furthermore, the surplus liquidity of the branches and their sales points (retailers) would be collected regarding the security issues of cash transport. The bank did not allow for the disclosure of the details of the amounts of the study; to solve this issue, the suggested algorithms were programmed into the software of MATLAB 2019a. Also, other sample matters were tested in a computer with a processor of 8.1 GHz core i5 and the main hard drive of 6 GHz in the operating system of Windows 10.

In the banking industry, the most important objective is customer satisfaction so, in the method of PROMETHEE, an ordinary function is used to reach this objective which shows that even a fractional improvement in this objective enjoys high significance. The U- and the V-shaped functions are also used to minimize the cost function and to emit GHG, respectively. Because in CIT, the small difference in the cost can be ignored as long as other objectives have significant improvements. In this paper, for solution algorithms to be comparable, the weight of the objectives is deemed equal. After the implementation of the algorithms on the objectives, the six metrics mentioned above are calculated, whose results are presented in Tables 4 to 6.

Regarding the presented results, it is visible that the MOGPA algorithm is more functional than algorithms NSGA-II and MOICA. The important point in this regard is that the Pareto solutions of the MOGPA outmatch those of others all through, which shows the higher quality of solutions in this algorithm. As an example, the comparison between the Pareto solutions of the three algorithms, whose results are inserted in Figure 4, clearly supports this claim.

TABLE 1. MOGPA parameter levels

Factor	Symbol	Level		
		-1	0	1
NFE	X_1	100000	200000	300000
nPop	X_2	80	100	120
p_c	X_3	0.6	0.7	0.8
p_m	X_4	0.3	0.35	0.4
nArchive	X_5	80	100	120

TABLE 2. MOGPA parameter setting values

Factor	Symbol	Coded value	Optimal level
NFE	X_1	0.6	26000
nPop	X_2	0.061	101
p_c	X_3	0.49	0.705
p_m	X_4	0.11	0.355
nArchive	X_5	0.72	101

TABLE 3. General information on sample issues

No. of problems	City	No. of treasuries	No. of branches	No. of ATMs	No. of retailers
1	Isfahan	5	6	53	6
2	Mashhad	5	5	49	5
3	Tabriz	5	5	47	3

TABLE 4. Computational results of the QM and MID metrics

	QM			MID		
	NSGA-II	MOICA	MOGPA	NSGA-II	MOICA	MOGPA
1	0.093	0.148	0.759	0.637	0.485	0.354
2	0	0.073	0.927	0.685	0.493	0.268
3	0.017	0.124	0.859	0.847	0.732	0.349

TABLE 5. Computational results of the DM and SM metrics

	DM			SM		
	NSGA-II	MOICA	MOGPA	NSGA-II	MOICA	MOGPA
1	0.842	0.878	1.245	0.784	0.641	0.508
2	0.849	0.904	1.368	0.860	0.607	0.492
3	1.101	0.937	1.073	0.827	0.580	0.372

TABLE 6. Computational results of the DEA and PM metrics

	DEA			PM		
	NSGA-II	MOICA	MOGPA	NSGA-II	MOICA	MOGPA
1	0.837	0.952	0.954	0.308	0.392	0.731
2	0.811	0.908	0.976	0.212	0.391	0.783
3	0.875	0.917	0.956	0.294	0.303	0.642

The most important characteristics of the algorithm MOGPA are management presuppositions which are neglected by other algorithms. In other words, through blending a metaheuristic and genetic algorithm with the PROMETHEE method, non-dominated solutions are gained which entail some of the characteristics which are targeted by the decision maker comprising the weight of the objectives as well as their preference function. In this regard, customer satisfaction, as well as costs, enjoy a higher priority than the pollution objective. Moreover, a little improvement in costs is not of high priority to the bank; for instance, when the cost of transport is high, expenses with a difference of lower than 1,000,000 Rials are deemed as the same to the bank and are not privileged by the tester. On the other hand, and in non-dominated sorting even one Rial saving in costs can dominate a response. In other words, using the PROMETHEE method in rating responses has caused data optimization of the location and – in the view of the manager - also closer condition to the reality, who is taking the threshold of indifference in the preference function. Because of this, the results emanating from the MOGPA are more functional.

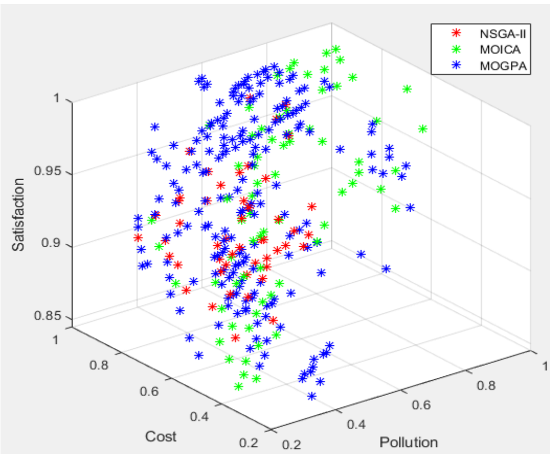

Figure 4. Pareto solutions for each algorithm

6. CONCLUSION

The model presented in this paper is a homogeneous one in the area of CIT for banks which considers both location and routing consistently and interrelatedly. In our presented model apart from minimizing cash transfer costs, we are after minimizing greenhouse emissions as well as increasing customer satisfaction. This model also takes into consideration the effects of traffic and its controlling impact on speed. As said earlier, this matter is an NP-hard one so solving bigger issues through exact optimization is not functional; as a result, a metaheuristic, multi-objective and novel algorithm in companionship with the genetic algorithm and PROMETHEE method were offered, together as the solution model. To assess the functionality of the presented algorithm, its Pareto solutions were compared with those of NSGA-II and MOICA in terms of six metrics of quality metric, mean ideal distance, spacing metric, diversification metric, data envelopment metric, and PROMETHEE metric; it was witnessed that in five indices of the quality metric, mean ideal distance, spacing metric, data envelopment metric and PROMETHEE metric, our suggested model surpassed the other algorithms with a wide margin and in terms of diversification metric, still its results were more acceptable than the other two.

For future potential research:

- We can view this problem as a simulation having in mind the demands of the customers so that in indefinite conditions, we can all the more get closer to real-life situations.
- Based on the opinions of the banking elite, significant and effective parameters can be transport costs, treasury construction costs, permitted capacity of cash transfer in the CIT vehicles, and the soft time window for each customer. As a result, through alterations in the number of parameters, we can evaluate the amount of creditability and sensitivity of the parameters, which are of more significance to the model.

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Persian Abstract

چکیده

انتقال وجه نقد از خزانه مرکزی به شعب بانک و خودپردازهای موجود در سطح شهر، یکی از فرآیندهای حیاتی در نظام بانکی است. عوامل متعددی مانند محل خزانه، ناوگان حمل، مسیرهای انتقال، پراکندگی جغرافیایی شعب و خودپردازها، توزیع تقاضای پول، رضایت مشتریان و ترافیک در انجام بهینه فرآیند انتقال پول مؤثر است. همچنین امروزه مسائل زیست‌محیطی به‌خصوص مبحث انتشار گازهای گلخانه‌ای موردتوجه قرارگرفته است. در این مقاله، یک مدل جدید از مسئله مکان‌یابی – مسیریابی وسایل نقلیه برای شبکه پول‌رسانی بانک بر مبنای ترافیک شهری توسعه داده شده است به‌طوری‌که هم‌زمان سه هدف کاهش میزان انتشار گازهای گلخانه‌ای، کاهش هزینه‌های مکان‌یابی و مسیریابی و افزایش رضایت مشتریان را در نظر می‌گیرد. علاوه بر این، یک الگوریتم ژنتیک ترکیبی چند هدفه جدید که با روش پرومته ترکیب شده است برای حل مدل پیشنهادی توسعه داده شده است. کارایی و اثربخشی الگوریتم پیشنهادی از طریق مقایسه با الگوریتم ژنتیک برمبنای مرتب‌سازی نامغلوب برای مسائل واقعی بانک سامان مورد بررسی قرار گرفته است. از آنجایی که مفروضات مدیریتی در توابع ارجحیت الگوریتم پیشنهادی در نظر گرفته شده است، نتایج نشان می‌دهد که راه‌حل‌های الگوریتم پیشنهادی کارآمدتر و نزدیک‌تر به واقعیت هستند.